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Obtaining Unique, Comprehensive Deep Seismic Sounding Data Sets for CTBT Monitoring and Broad Seismological Studies

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14. ABSTRACT

In cooperation with the Center for Geophysical and Geoecological Studies (GEON, Moscow, Russia), the University of Wyoming and now also with the University of Saskatchewan digitized, edited, transferred into standard digital formats, and delivered to public domain seismic records from 12 major Deep Seismic Sounding (DSS) projects acquired in 1970-1980's in the former Soviet Union. The data include 3-component records from 22 Peaceful Nuclear Explosions (PNEs) and over 500 chemical explosions recorded by a grid of linear, reversed seismic profiles covering a large part of Northern Eurasia. Digital copies of all records were delivered to AFRL and to the Incorporated Research Institutions for Seismology Data Center for unrestricted distribution to researchers. The availability of the DSS PNE datasets resulting from this project, combined with the recent results arising from them (velocity, reflectivity, Receiver Functions, mantle attenuation, Lg Q, P- and Lg coda Q, scattering, phase amplitude ratios, empirical first-arrival travel times) makes the area of PNE profiling one of the best-constrained seismically at short periods, both for structural studies and for nuclear test monitoring.

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1. OBJECTIVE AND SCOPE

The objective of this research was to create digital copies of seismic records from most of DSS datasets preserved to date, and to provide full and unlimited access for the broad seismological community to them. This task was approached through a long-term cooperation between the University of Wyoming seismology group and Center GEON, Moscow (a division of Spetzgeofisika at the time of data acquisition, now a division of Vniigeopfisika). In this cooperation, the records were digitized at GEON, who also provided tables of channel amplifications and other information. We performed the consultations with GEON, data transfer, all the primary data reduction, reformatting, and quality control. The digital records were later submitted to the Incorporated Research Institutions for Seismology (IRIS) and incorporated in its global on-line databases.

Twelve DSS PNE projects were selected for this work as the most important and relatively recent (Figure 1, west to east): AGATE, BATHOLITH-2, RUBY-1 and 2,

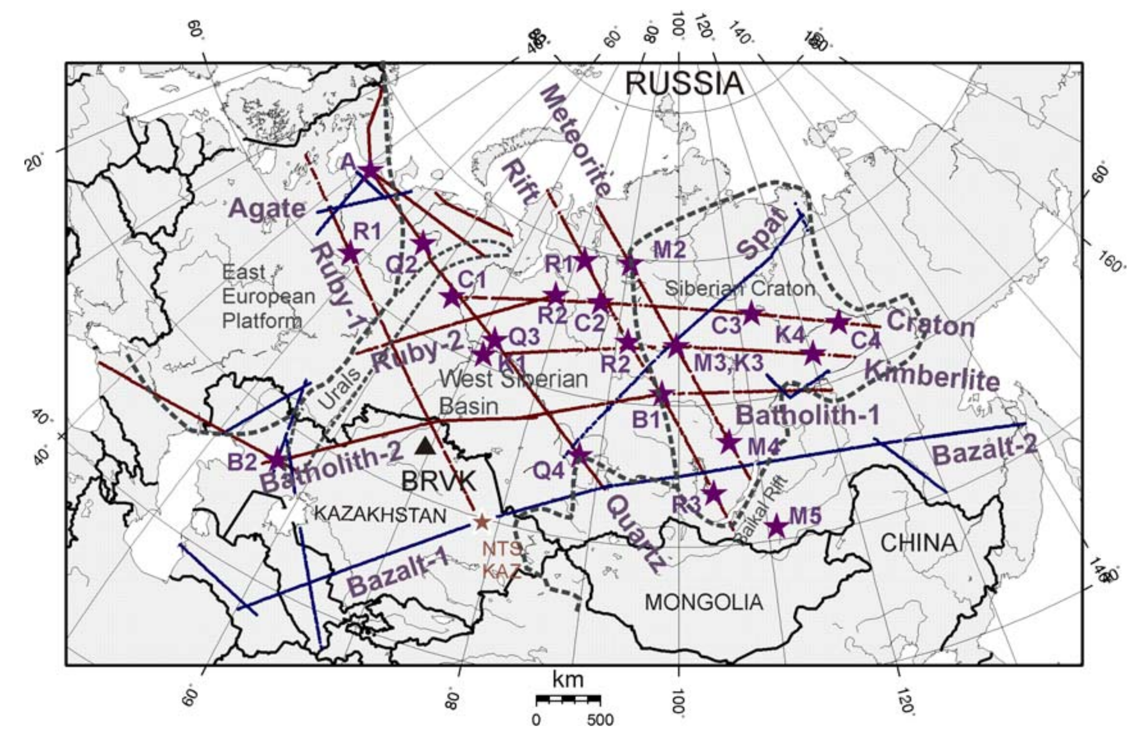

Figure 1. Twelve DSS PNE projects delivered to the public domain as a result of this project (blue labels). The PNEs (large stars) are labeled using the first letters of the corresponding profiles names and PNE number (for example, Q2 stands for PNE QUARTZ-2. PNE AGATE is shown without a number). The coordinates and other parameters of the PNEs used in these profiles were reported by Sultanov et al. (1999). Colored triangles in the profiles represent the recording stations. Typically, 30-50 chemical explosions were also recorded in each profile. Major tectonic units are indicated. The Semipalatinsk nuclear test site is indicated (NTS KAZ), and the Borovoye IMS station is also shown (BRVK).

Note the extent of systematic, continuous profiling, with PNEs (labeled stars) detonated at the intersections of a 2-D grid and recorded in two, and often in four directions.

BAZALT-1, QUARTZ, CRATON, KIMBERLITE, RIFT, METEORITE, BATHOLITH-1, and BAZALT-2. Later in the project, it became apparent that the chemical-explosion recordings from project METEORITE suffered too many data gaps, and the chemical-explosion part of dataset SPAT was obtained in replacement of the obligations of this project.

The remainder of this report is organized as follows. After a brief summary of the Deep Seismic Sounding program in the former Soviet Union, we provide a sketch of geological and tectonic structures covered by profiling. After this, we summarize each of the individual datasets, similarly to the descriptions provided with our data distributions to IRIS. In *Conclusions*, we also offer an outlook on the continuation and possible future directions of this important work. Finally, we provide lists of bibliography of studies using the PNE profiling data and also (incompletely) covering a number of subjects on which the DSS PNE datasets have provided the most significant impact.

2. THE DEEP SEISMIC SOUNDING PROGRAM

The Deep Seismic Sounding (DSS) program carried out by Soviet scientists from 1960's to 1990's remains a unique source of seismic datasets allowing a detailed study of the seismic structure of the upper mantle. Long-range seismic refraction/reflection profiles covered nearly the entire territory of the former USSR, and amounting to about 1/6 of the whole continental lithosphere (Figure 1). This unique network of geophysical profiles with an overall length of 150,000 km utilized nearly 60 Peaceful Nuclear Explosions (PNEs) specially designed and set-up for seismic purposes, along with hundreds of powerful chemical explosions (Figure 1). The power of explosions ranged from tens of kilograms to 4,000-15,000 kg for chemical explosion (Solodilov, 1997, Egorkin et al., 1991, Kozlovsky, 1990.) and 7-20 kiloton for nuclear explosions (Fujita, 1995; Sultanov et al., 1998).

Large chemical explosions and PNEs were recorded by densely spaced (10-15 km) 3-component, short-period (1-2 Hz) portable analog recording systems. Recording ranges of PNEs exceeded 3200 km, allowing observations of seismic phases diving down to 800 km into the mantle (Egorkin and Pavlenkova, 1981; Ryaboy, 1989; Kozlovsky, 1990).

Acquisition of DSS datasets was among the principal scientific priorities of the Soviet government. A special institution—the Special Regional Geophysical Expedition, or Spetzgeofisika, later known as the Center GEON (Center for Regional Geophysical and Geoecological Research, and now a division of VniiGeofisika)—was established for this purpose. A comparable project using nearly 60 nuclear explosions and helicopter support across thousands of kilometers of extremely difficult sub-Arctic terrain would have cost billions of dollars on a Western economy. It is very unlikely that a seismological project of a similar scale will be undertaken in a near future (Fuchs and Wenzel, 1997). For these reasons alone, the preservation and the maximum use of the DSS data constituted one of the priorities in today's seismology. Since all of the recordings were performed on magnetic tape in analogue format, the danger of loss of this invaluable data set was great. The seismological group lead by Professor Scott Smithson of the University of Wyoming was the first to start the cooperation with the GEON center in Moscow to digitize to their full length, the records from nuclear and chemical explosions from the profile QUARTZ.

Also, the Geophysical Institute of Karlsruhe University and the GeoForschungsZentrum at Potsdam started a joint program with GEON to digitize data from other profiles (Fuchs & Wenzel, 1997).

The most important reason for applying every effort to the analysis of DSS data is that these data cover the intermediate range and provide the link between traditional wide-angle and regional and teleseismic seismology. The energy of the sources and the depths and distance coverage of 3-component recordings is far beyond the limits of any other branch of controlled-source seismology, whereas the linear geometry and density of the profiles is still far above the level provided by seismological networks. DSS interpretations provide practically the only source of information for high-resolution imaging of the upper mantle and are a major resource for demonstrating its profound heterogeneity. Most importantly, in most of the DSS profiles along with the PNE records, a very comprehensive crustal dataset using large chemical explosions was acquired, providing images of the crust that are sufficiently detailed to allow a robust inversion for the deeper mantle structures.

DSS data are unique in the length of continuous profiling, in the strength of the explosions used, in the number of source points (the combination of nuclear and chemical shots along the whole profiles), and in the recording in two to four directions from each source point (Figure 1). Dense station spacing and known positions of the explosions allow me to resolve the velocity and attenuation structure of the upper mantle in unprecedented detail compared to earthquake data.

Earlier publications in English of some of the DSS results obtained using various data processing techniques including non-linear velocity filtering and travel time analysis include Belyayevsky et al. (1976), Kats et al. (1978), Vinnik et al. (1978), Yegorkin et al. (1978), Chernyshev et al. (1979), Yegorkin et al. (1979), Yegorkin and Yegorkina (1980), Vinnik and Yegorkin (1981), Yegorkin and Pavlenkova (1981), Yegorkin et al. (1981), Fuchs and Vinnik (1982), Pavlenkova and Yegorkin (1983), Yegorkin and Chernyshev (1983), Koshubin et al. (1984), Burmakov et al.(1986, 1987), Egorkin et al. (1987), Alekseev et al. (1988), Egorkin and Sumerina (1988), Egorkin and Zyuganov (1988), Egorkin (1989), Galdin et al. (1989), Ryaboy (1989), Egorkin and Mikhaltsev (1990), Kopnichev and Dyatlikova (1990), Vinnik et al. (1990), Yegorkin et al. (1991), Benz et al. (1992), Yegorkin (1992), Yegorkin and Kostuchenko (1992), Yegorkin et al. (1992). More recently, Schueller et al. (1996) used a travel-time, refraction-reflection tomography to invert for the *P*-wave velocity structure of the northwestern part of the profile QUARTZ, Ryberg et al. (1996) presented a 2-D interpretation based solely on the first arrivals from QUARTZ PNEs, Lorentz et al. (1997) applied tomographic inversion to the mantle arrivals from QUARTZ PNEs, and Ryberg et al. (1998) stacked all available DSS records to derive a “generalized” 1-D regional velocity model of northern Eurasia. Mechie et al. (1997) compared the observations of the asthenospheric LVZ in a number of DSS profiles, and Egorkin (1997) presented evidence for observations of the 520-km discontinuity on most of the DSS profiles. The progress in the understanding of the heterogeneity of the upper mantle structure through controlled-source and passive seismology was summarized in the 1997 EUROPROBE conference (Fuchs, 1997). Recent work focused on integration of the results into 3-D pictures of the lithosphere (Morozov et al., 2001), analysis of the Siberian profiles (Pavlenkova et al., 2002;

Pavlenkova and Pavlenkova, 2007), analysis of mantle and crustal scattering, receiver Functions, and coda properties (e.g., Ryberg et al., 1995; Morozov et al., 1998a; Morozov and Smithson, 2000; Morozov, 2001; Nielsen et al., 2003; Nielsen and Thybo, 2003). Several longer-offset PNEs (BATHOLITH-2, CRATON-1, QUARTZ-4; Figure 1) produced reflections from the core-mantle boundary.

Two fundamental general conclusions were drawn from DSS studies. First, a number of 1-D mantle models derived for the Northern Eurasia (Mechie et al., 1993; Priestley et al., 1994; Pavlenkova, 1996) exhibit a prominent low-velocity zone (LVZ) below about 200 km depth and probably reduced velocity contrast at the 660-km boundary compared to the IASP91 model (Ryberg et al., 1998). There is no general agreement about the sharpness of the mantle transition zone discontinuities which is critical to understand their cause in terms of mantle mineralogy and composition. Mechie et al. (1993) and Ryberg et al. (1998) modeled the 410-km discontinuity as a sharp transition consistent with the IASP91 model, but Priestley et al. (1994) argued that the 410-km discontinuity may actually be a 35-km thick transition zone.

Another important result of DSS studies is the demonstration of strongly heterogeneous, 2-D structure of the uppermost mantle within the regional scale and down to at least 400 km (Mechie et al., 1993; Priestley et al., 1994; Ryberg et al. 1995; Morozova et al., 1997, submitted). This heterogeneity manifests itself in the velocity and attenuation structure (Morozov et al., 1998b), as well as in the properties of regional and global mantle boundaries (Pavlenkova, 1996; Morozova et al., 1999). The variability of the uppermost mantle partly limits the significance of 1-D regional models and partly minimizes some of the controversies in interpretations; on the other hand, this variability demands (at least) 2-D interpretations, of which very few exist at the regional scale.

In the context of nuclear test monitoring research, our group at the University of Wyoming and currently – at the University of Saskatchewan emphasized a variety of empirical mapping approaches. The following models were devalued in the recent years from integrated interpretations of multiple profiles. These results were principally sue to the DSS PNE data becoming available through the present project:

1) An empirical 3D first-arrival travel-time model (Morozov et al., 2005) suitable for generation of reference Source-Specific Station Correction surfaces;

2) Phase amplitude ratio maps, including quantitative correlations with crustal properties (Li et al., 2007);

3) An empirical *Lg Q* model (Li et al., submitted to BSSA). As above, significant correlations with parameters of crustal structures were fund, such as correlations of *Lg Q* variations with the presence of sedimentary basins and Moho depth gradients;

4) *P* and *Lg* coda *Q* models (Morozov et al., submitted to BSSA, a and b). Notably, in these studies, we propose a different description of frequency dependent coda *Q* that is physically consistent, results in stable and transportable estimates, allows a direct correlation to the *Lg Q* studies above, and correlates well with regional tectonics;

5) Corner-frequency and magnitude-yield analysis of the PNEs (Li, Morozov, and Smithson, in preparation for BSSA).

3. TECTONIC AND GEOLOGIC SETTING

The main part of the territory of the former USSR consists of ancient blocks of different dimensions joined by foldbelts into a single continent. The East European and Siberian platforms played the major role in the accretion of the territory of former USSR. These great platforms are bordered on the south by African-Arabian, Indian, Tarim, and North-Chinese continental blocks.

3.1. East European Platform

The East European platform (Figure 1) is about 3000 km across, with a basement formed at 1600 Ma (Zonenshain, 1990). The platform is mostly surrounded by fold belts. These are in the north the Caledonian belt and Timan belt; in the east the Uralian belt; and in the south the Mediterranean system. Young orogenic uplifts are absent in the East European platform. According to Zonenshain et al. (1990) the Precambrian basement of the platform is characterized by a number of angular blocks 100 to 300 km wide separated by suture zones. These blocks are mainly composed of Achean granite-greenstone and granite-gneiss domains. The recognized blocks of the Baltic Shield occupying the northeastern part of the platform are the Murmansk, Kola, Belomorian (White Sea), Svecofennian, and Sveconorwegian blocks. These blocks experienced deformation and metamorphism at 2500-2600 Ma (Khain, 1977, Bibikova, 1989). An exception is the Svecofennian schist-gneiss block of the Baltic shield which was mainly deformed at 1700 Ma. The isotopic age of the greenstone belts range from 3250 to 3000 Ma (Bibikova, 1989). The last significant event affecting the east European platform was the intrusion of the rapakivi-type granites at 1.5-1.6 Ga. The basement is interrupted by narrow and deep aulocogens which formed graben-like trough structures. Formation of approximately eight grabens occurred during the Middle Proterozoic and Late Paleozoic.

The **Baltic Shield** or Fennoscandia located in the northeast of the platform is the largest and the most stable structural element of the craton (Gaal and Gorbatschev, 1987). It lacks any significant sedimentary cover and youngs from NE to SW. The rocks of granite-greenstone areas in Baltic Shield underwent later metamorphism and deformation simultaneously and were intruded by granites and tonalites. The granites intruded into greenstone belts of the Karelian block are 2740 Ma (Shcherbak and Bibikova, 1984). The primary relationships between greenstone complexes and granite-gneiss cupolas are overprinted by later metamorphism, granitization and folding.

In the Baltic Shield the profile Quartz starts at the Kola megablock, passes the Imandra-Varguza suture zone and continues toward the White Sea in the southeast along the granulite belt in the Belomorian (White Sea) megablock. There were no records from the White Sea area from the Quartz profile.

The Kola megablock occupies nearly the entire peninsula, except the southern coast which belongs to the Belomorian (White Sea) megablock. The oldest rocks of the megablock include those of the Kola series; they are represented by biotite and garnet-biotite gneisses, amphibolites, and amphibolitic gneisses. Metamorphism corresponds to amphibolite and partly granulite facies conditions. Dating giving an age of 3,300 Ma was obtained for crystalline schists of granulite facies. This is regarded as the age of the earliest metamorphism of the Kola series. The structure of the Kola series is complex; it consists of folds of many orders, complicated by faults and magma intrusions. The oldest granite-gneiss basement is on average of tonalitic composition.

The Imandra-Varguza zone separates the Kola from Belomorsky block. This suture zone is about 40 km wide and the age of the rocks is estimated as 1900-1800 Ma and the age of metamorphism as 1800-1700 Ma. The section is made up of thick diabase sequences with intervening meta-clastic sedimentary and meta-volcanic rocks, together with gabbro and ultramafic rocks (Novikova, 1975). According to Novikova, many rocks constituting the suture zone are similar to ophiolites suggesting the presence of an oceanic basin in Jatulian time separating the Kola and Belomorsky blocks.

The White Sea (Belomorian) megablock underlies the greater part of the White Sea. The White Sea series consists of various gneisses, mainly biotitic and garnet biotitic. Crossing the shallow White Sea with a water depth of less than 50 meters the seismic profile goes further to the sediment-covered structures of the northeastern East European Platform.

Mezenskaya depression. The East European platform basement is interrupted by narrow and deep (more than 3 km) graben-like troughs called aulacogens or failed rifts. The Mezenskaya Depression (Mezen' Syneclise, or Mezen' Basin), is situated in the northeastern part of the Russian platform between the eastern slope of the Baltic Shield and the Timan belt. Aulacogens originated in a period of drastic break-up of continent. According to the hypotheses of Burke's and Wilson (1977), aulacogens are failed arms of three-arm rift systems. The Mezen' graben is parallel to the trend of the continental border which presumably records divergence. It originated in Riphean time (about 1600-850 Ma). According to Zonenshain (1990) in the Middle-Late Riphean time, new oceanic basins came into existence east of the present East European platform at the site of Timan and the Urals. The development of the Mezenskaya depression continued with interruptions to the end of the Jurassic and beginning of the Cretaceous, after which it became involved in the general uplift of the northern part of the Russian platform (NE part of the East European platform). The deep structure of the Mezenskaya depression was little known untill recently when seismic profiling including DSS were carried out.

3.2. Timan Fold Belt and Timan-Pechora Basin

The northeast boundary of the East European platform is the Late Precambrian **Timan fold belt** with a NW-SE trend which extends from the Scandinavian Caledonides in the northwest to the Urals in the southeast (Figure 1). The low (up to 463 m) and fairly wide (up to 150 km) ridge is a large uplift of the Riphean basement of the Timan-Pechora platform. Along the surface of the basement the Timan fold belt forms a flat and wide asymmetric uplift with steeper and narrower southwestern, but wider and steeper northeastern limbs. It separates the Barents massif (Timan-Pechora platform) from east Europe and may be considered as a suture between East Europe and the minor Barentsia continent, resulting from the collision at the end of Precambrian.

The second very large structure of the Timan-Pechora Platform is the Timan-Pechora Basin which occupies the remaining part of the Timan-Pechora Platform. Zonenshain et al. (1990) treat the Timan-Pechora Basin as a part of the Pechora-Barents Sea Basin which incorporates basins of several different ages including the entire offshore area of the northern Barents Sea (800,000 km) in the system of sedimentary basins.

The Timan-Pechora Basin occupies swampy low areas north of the Arctic Circle exceeding 350,000 km^2 onshore. It occupies the extreme northeastern part of the Russian Plain with the northwest-southeast trending Timan belt separating it from the east European Platform (Figure 1). The Basin is bounded on the east by the Northern and Polar Urals and in the north by the Polar Ocean. The Timan-Pechora Basin is an important oil and gas region, and the Timan belt contains large bauxite deposits. The 120 oil fields known today represent one of Russia's richest hydrocarbon reserves (Belonin et al., 1990, Clarke, 1994). The QUARTZ profile crosses the southern part of the basin (sometimes called Izhma-Pechora Basin) near the Timan-Pechora deep borehole at the eastern foot hills of the Timan belt.

Similar to another great sedimentary basin, the West Siberian basin, deep erosion of the underlying Precambrian and Paleozoic basement of Timan-Pechora Basin was followed by subsidence due to extension of the continental crust within aulacogens or rifts (Zonenshain et al.). The existence of remnants of oceanic crust as part of the basement structure is suggested. This underlines the basin's origin as failed rift system of not fully developed oceanic structures. The basin represents a distinct tectonic evolution which suggest a different crustal structure than for the ancient platform regions of eastern Europe and Siberia.

The platform area was formed during late Precambrian as part of an ancient craton which probably united the Eastern European and the North-Asian craton (Khain, 1985). The late Precambrian rifts filled with sedimentary rocks during the Proterozoic. In middle Riphean time, the platform was part of the Ural-Timan Geosynclinal Belt. Rifting processes correlated with crustal extension and formation of oceanic crust. They were followed by subsequent ocean closure and collision of the adjacent continental masses. The platform includes basins of ages ranging from early Devonian to late Cretaceous and early Paleogene. It underwent several extensional events from Devonian to Paleocene. The basins consist of several broad depressions separated by narrow uplifts. In the middle Paleozoic (about 400 Ma), the Pechora-Barents Sea rift system originated and subsidence of the lowland began.. Extension of the unconsolidated basement structure, greater mobility, and deformation, as well as accumulation of sediments was widespread in the Triassic (245-230 Ma). With the end of the evolution of the adjacent Uralian fold system in middle Mesozoic, the platform area became a part of the consolidated region connecting the basin with the Polar Urals and the West Siberian basin, and created a part of the large tectonically stabilized region of northwestern Eurasia.

The maximum thickness of the sedimentary cover is 16-18 km in the South Barents sea depression with an average of 5 to 6 km of the upper Paleozoic and 8-9 km of Triassic sediments.   The sedimentary layer in the Pechora Basin is thinner, reaching 4-8 km on average.

3.3. Uralian Fold Belt

The **Urals** (Figure 1) represent a linear collisional fold belt formed during the Late Paleozoic and extended into the early Mesozoic, and it is probably one of the best preserved Paleozoic orogens in the world. It developed out of a sequence of oceanic closing, subduction of oceanic crust under island arcs, convergence of lithospheric plates, and continental collision. The Uralide orogen is distinct from other Paleozoic orogens because it has a pronounced crustal root (Thouvenot et al., 1995, Knapp et al., 1996); relatively minor syn- or post-collisional extension; low terrestrial heat flow (20-30 mW/m^2); and well-preserved ophiolite and volcanic-arc assemblages (Ivanov et al,, 1991; Steer et al., 1995, Thouvenot et al., 1995).

Tectonic evolution of the Urals began with rifting and development of a passive continental margin on the East European platform in latest Cambrian to early Ordovician time, followed by Middle Paleozoic rifting of microcontinental fragments, the formation of island arcs and back-arc basins, and assembly of these terranes within the Uralian paleo-ocean. (Ivanov et al., 1991, Zonenshain et al., 1984, 1990). The final collision of Eastern Europe with this complex collage and Siberian craton took place in Late Carboniferous and Permian time (310-270 Ma). Proterozoic and Paleozoic terranes were partly metamorphosed and intruded by granitic plutons when the continental collision occurred. The neotectonic re-activation of the belt is a long-term effect of Cenozoic uplift. with present uplift rates of about 2 mm/yr and significant historical seismicity (Ryzhiy et al., 1992).

The Urals trend north-south, 400 to 500 km between the East European Platform in the west and the West Siberian basin, the Siberian craton, and the Central Asian belt system in the east. Extending 2500 km from the Kara and Barents Sea in the north to the Mugodzhary range in the south, the fold belt shows fairly gentle topography with maximum elevation of less than 1900 meters in the northern Urals. The fold belt is divided in the Southern, Middle, Northern and Polar region correlating to different structural ages and tectonic histories; the *Quartz* profile crosses the Northern Urals. The northern section shows a thick Mesozoic and Cenozoic cover over the Paleozoic folded basement. The Ural super-deep borehole (SD-4) is located in the middle Urals south of the profile. The Southern and Middle Urals are the best studied regions; they contain one of the oldest known and richest ore deposits of Russia.

Zonenshain et al. (1984,1990) divide the fold belt into western, lower, autochthon *externides (*Uralian foredeep*)* including the eastern margins of the basement of the east European Platform and in eastern, upper, allochthon *internides* containing Paleozoic oceanic and island-arc complexes. While the fold structure of the internal segments was completed by the end of the Carboniferous or the beginning of the Permian (290-270 Ma), folding in the external segments went on up to the Triassic (248-213 Ma). The two zones are separated by the Main Uralian fault zone measuring a few to 20 km in width. The fault dips to the east at the angles from 20^0 to 40^0 and is seen on seismic records to depths of 7 km (Zonenshain, 1990).

The *externides* encompass the Pre-Uralian foredeep filled with Permian molasse and the thrust domain situated between the fordeep and the Main Uralian fault. This domain consists mainly of Uralide complexes of two types (Puchkov, 1979): 1)shelf complexes and 2)abyssal and bathyal complexes. Both are strongly deformed, often include nappes and are overthrusted by large allochthonous masses. The Uralian *internides*, situated eastward from the Main Uralian fault, consist of a number of parallel zones aligned along the N-S foldbelt direction. To the east from the Main Uralian fault a series of troughs and synclinoria constitutes the so-called greenstone belt of the Urals, composed of island arc and oceanic rock complexes. Volcanic and volcanogenic-clastic sequences predominate at nearly all stratigraphic levels from the Silurian to Middle Carboniferous. The lower part of the section is composed of ophiolite complexes and the upper one of volcanic rocks of the calc-alkaline series. While the lower complex is oceanic, the upper one is island-arc, showing that island volcanic arcs were built upon an oceanic basement. The ophiolite sequence in the Urals contains metamorphosed harzburgites below, an overlying layered complex, gabbro, sheeted dikes, pillow lavas, and sediments. Island-arc complexes are distributed over the entire internal zone of the Urals and consist mainly of basalts. In the south, the belt consists of calc-alkaline volcanics, andesites, andesite-basalts and dacites, which are intruded by diorites and granodiorites.

The folded structure of the internal Uralian zones was completed by the end of the Carboniferous or the beginning of the Permian (310-270 Ma), as shown by the emplacement of many cross-cutting granitic batholiths and the formation of granite-gneissic domes. In the external zone, folding continued up to the Triassic. The existence of a crustal root beneath the Urals and the relative lack of large-scale extension fabrics and structures suggest that the Urals have not been significantly extended.

3.4. West Siberian Basin

Bordering the northeast of the Uralian fold system, the West Siberian Basin is the largest structural element of this kind on our planet. A continuous layer of mostly continental Quaternary sediments, averaging 10 km in thickness in the north and 3 km in the south, covers over 3.4 million km^2. The basin forms a large, shallow bowl extending 2300 km north-south and from 700 to 1900 km in west-east direction. It is bounded in the east by the Enisei range and Siberian Platform, in the north by Kara Sea and in the south by the Central Asian fold belt and the Altay-Sayan region.

The evolution of the basement structure is not well understood. It is believed that the basement was formed by Paleozoic fold structures of various ages and older Precambrian blocks (formed 1.6 Ga ago). The existence of oceanic crustal elements, remnants of the Ob' Paleo-Ocean (it was a result of separation of the Eastern European and Siberian cratons) with ages of about 220 Ma, is provided by numerous bodies of mafic and ultramafic rock which probably form part of ophiolitic complexes and were discovered from drilling data (Zonenshain, 1990, Khain, 1994). The western edge of the platform overlies the continuation of the eastern zones of the Urals which determines its deeper structure and age.

A considerable role in the structure of the West Siberian Platform is played by continental sedimentary-volcanic formations filling graben-troughs (rifts) in the basement. These thick sediments covering Triassic grabens make the understanding of the nature of the basement, especially in the north, fairly difficult. These grabens are 150-200 km long; however, the true length of many of them is not known. The depths of several depressions are 1-4 km.

Thick Cenozoic and Mesozoic sediments built the basement cover. Triassic and Holocene formations reach 10 to 12 km in the north while the oldest sediments found in the central and southern parts of the basin are Jurassic (210-150 Ma). They are built of up to 6 to 7 km thick alternations of shallow-water marine and continental facies.

Uplifts and depressions of large and medium size are complicated by hundreds of local uplifts. Their transverse dimensions vary between a few km and tens of km; their height is usually 60-100 m. The most active growth of uplifts occurred during the Late Jurassic and Neocomian, uplifts near the Altay-Sayan region again increased in the Paleogene and Neogene.

The West-Siberian Rift (Pur-Guden Basin, Figure 1which is located on the northwestern edge of the Siberian platform, is a failed oceanic rift developed in the Triassic. Since the cessation of extension, the West-Siberian Rift was filled by up to 13-km thick sediments (Cipar et al., 1993; Aplonov, 1995).

The thickness of the crust and the velocity at the Mohorovocic discontinuity decreases from the edges to the central part of the platform. Thinning of the Earth's crust and decrease of the mantle density, confirm the riftogenic origin of the West Siberian Basin (Khain, 1994).

Large discoveries of oil and gas deposits in the last 20 to 30 years reveal the economic significance of the West Siberian basin.

3.5. Altay

The Altay-Sayan folded region occupies the area between the Kazakhstan-North Tien-Shan region in the SW, and southwestern fringe of the ancient Siberian Craton in the northeast, and its continuation in the northwest is concealed by the vast Mesozoic cover of the West Siberian Basin. The Altay-Sayan is composed of a number of different units assembled by accretion of island-arcs to the Siberian craton at somewhat different times but generally in the Late Precambrian and Paleozoic. The crustal thickness ranges from 36 to 55 km and in most areas 40-45 km (Beloussov et al., 1992a, b).

The Altay-Sayan region traditionally has been divided into domains based on the ages of deformation. The profile QUARTZ crosses Altay along the Minusinsk zone that belongs to the domain of Early Paleozoic deformation which underwent Early or Middle Cambrian folding. The Minusinsk zone developed as one or several volcanic island-arcs originated on the oceanic floor of the Paleo-Asiatic ocean in Early Cambrian time. In the Middle Cambrian the Tomsk continent (or its fragments) collided with the island arcs. The ophiolite basement of the arcs and the island arcs themselves were partially thrust over the Tomsk continent. This accretionary complex was produced from fragments of continents and island arcs. Prior to the Late Cambrian, the accretionary mosaic collided with the passive margin of Siberia and was thrust over it. The consequence of this collision was the folding throughout the Minusinsk fold zone. The collision of India and Eurasia led to uplift of the foreland blocks including Altay and Tien-Shan mountains. The age of the root maybe associated with the Mesozoic uplift. Altay attained its present elevation during the middle Cenozoic as result of collision of India with Eurasia to form the present Altay, Tien-Shan and Forebaikalia. The rate of this uplift increased gradually from the Oligocene to the Pleistocene (Khain, 1994).

3.6. Siberian Craton

The Siberian Craton (Figure 1) is ~2500 km across and is mainly represented by its Archean basement. Two shields (Aldan and Anabar) and three deep basins (the Tunguss and Low-Angara Basins, and Vilyui Depression) are identified within this craton. The western part of the Siberian Craton is generally covered by a ~5-6 km sedimentary cover containing 100-150 to 1400-m thick flood basalts of the Mesozoic Siberian Traps (Czamanske et al., 1998; Pavlenkova et al., 2002). Within the Tunguss and Low-Angara Basins, the sedimentary cover is up to 10-km thick (Egorkin et al., 1987; Pavlenkova, 1996; Pavlenkova et al., 2002). The Tunguss Basin is filled with a high-velocity ($V_P \approx 5.5$ km/s) Devonian sedimentary cover with a relatively flat Moho at ~50 km depth in the north (Egorkin et al., 1987; Pavlenkova, 1996), but a ~3-5-km Moho uplift in the south (Pavlenkova, 1996). The Low-Angara Basin is filled with both Paleozoic and Mesozoic sedimentary cover with lower velocities ($V_P \approx 5.2$ km/s), and the basement subsidence is compensated by a ~3 km Moho uplift (Pavlenkova, 1996; Pavlenkova et al., 2002). The Vilyui Depression is filled with ~10-14 km of loose and low-velocity Mesozoic rocks ($V_P \approx 2.5$-4.5 km/s), and the basement surface shows steep dips with a localized up to 13-km uplift in the Moho (Egorkin et al., 1987; Pavlenkova, 1996). The crustal thickness is 40 to 45 km on the average (Pavlenkova, 1996), increasing to 50 km below the Tunguss Basin, and ~35 km below the Vilyui Depression (Egorkin et al., 1987; Pavlenkova, 1996; Pavlenkova et al., 2002).

On the SE edge of the Siberian Craton, **the Baikal Rift zone** (BRZ; Figure 1) is superimposed on the Baikal fold belt and is composed of a chain of Late-Cenozoic half grabens extending over a distance of ~1500 km. This S-shaped suture is situated along the edge of the Siberian Craton (Logatchev and Zorin, 1992; Hutchinson et al., 1992; Zorin et al., 2003). It is seismically active and is still rifting. The Late-Cenozoic sediments are usually 2.5–3 km thick and reach up to ~7 km thick in the rift basins (Logatchev and Zorin, 1992; Hutchinson et al., 1992). The heat flow in the Baikal Rift is 60-75 mW/m^2, which is much lower than in other continental rifts (usually > 100 mW/m^2, Ionov, 2002). The crustal thickness beneath the BRZ is 35-45 km (Dehandschutter, 2001).

4. RESEARCH ACCOMPLISHED

4.1. Data Acquisition and Processing

DSS data were recorded using specially designed three-component seismographs “Taiga” (the name means the Russian sub-Arctic coniferous forest) and “Cherepakha” (Turtle) that were specially designed for the program. The systems equipped with NTS-1 geophones (Figure 2) were deployed by helicopters at a nominal spacing of

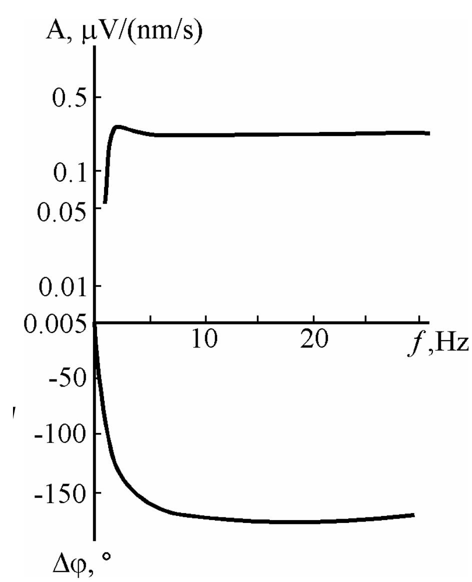

Figure 2. Amplitude and phase responses of “Taiga” recorders with NSP-1 seismometers used in DSS PNE recordings (after Ryaboy, 1989).

Figure 3. PNE analog magnetic tape data storage at Center GEON (2004).

10-15 km along the whole length of each profile and radio-controlled to simultaneously record the waves at distances of up to 1500 - 3000 km. Designed for 7 to 10 days of continuous recording of the ground motion velocity, the stations operated at 0.5 - 20 Hz frequencies within a dynamic range of 70 dB (Figure 2; Ryaboy, 1989; Solodilov, personal communication, 1997).

From early 1990's, GEON went through a number of turbulent reorganizations, lack of funding, retirements of the key personnel, and disputes about its building in downtown Moscow. All this certainly did not improve preservation of the historic Soviet-era PNE datasets (Figure 3). Fortunately, principally owing to the present project, GEON specialists had been able to survive this period and continue recovering and digitizing the datasets (Figure 4a,b).

During pre-processing PNE data, we encountered a number of difficult processing problems that were related to the unusual parameters and format of the records. In order to tackle these basic data manipulation tasks, we wrote a suite of tools for the CogniSeis® DISCO seismic processing system, which was the main seismic processing system running on the dedicated VAX 11/785 in the University of Wyoming Reflection Seismology group until 1997. Later, these tools were incorporated into a new processing system called SIA (http://seiswev.usask.ca/SIA), whose further development was in fact largely inspirited by the needs of the DSS data projects.

The PNE datasets were digitized from 1994 -2005 at Center GEON in Moscow. Digitization was performed to the full length of the analog records varying from about 100 sec for near-shot receivers to over 600 sec in far-offset PNE records. During the

Figure 4a. Playback and digitizing system for CHEREPAKHA seismographs (GEON Center, Moscow, 2004).

early stages of digitization, the digitizing equipment and software were not able to handle such long records, and so the records were split into several segments with 20-25 sec overlaps. Another complication of the initial data reduction was the shipment of the records to the University of Wyoming in four different Russian formats, none of which could be read using the existing software. The time starts, coordinates, gain factors and other parameters of the records were provided in a form hardcopy tables which we checked and loaded manually.

After the resulting records were delivered to the University of Wyoming, the parts of the records were concatenated using a cross-correlation technique that allowed to locate the exact time starts of the record segments. At the same time, however, DISCO (a commercial seismic processing system designed for 2-D CMP exploration data processing), was not able to handle the long (up to 30,000 samples per record) DSS records, and an interface had to be developed to allow splitting the records into smaller segments while allowing the processor to manipulate the long data traces in their integrity. These complications mostly affected the QUARTZ records; other datasets were provided by GEON in custom “DSS” formats.

Having loaded the data into DISCO, and later – into SIA, we performed a tedious data editing procedure. This step involved plotting and inspection of all data records and selection of the channels with best dynamic parameters. Typically, the DSS data were recorded into 6 channels at each recording point at 2 different gain levels. This allowed selection of the channels that were not overloaded and had better signal/noise ratios. This procedure was performed using manual editing, which took considerable time.

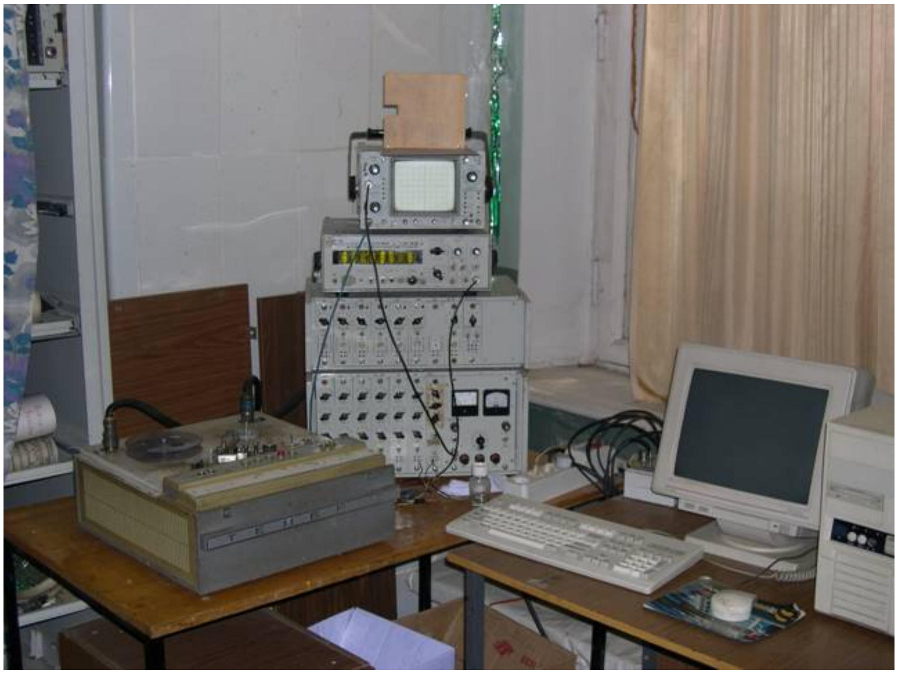

Figure 4b. Playback and digitizing system for TAIGA seismographs (GEON Center, Moscow, 2004).

Many of the processing steps included in my data analysis require 3-component data. However, all three components of the recorded wavefield were not available for all stations; occasionally, some channels were missing. Given virtually no support for multicomponent data manipulation offered by the DISCO system, this irregularity (which is typical for wide-angle multicomponent data sets) of the data also caused a substantial difficulty for advanced signal analysis. This difficulty was overcome by the development of a series of special computer codes.

After the VAX 11/785 was taken out of operation in early 1997, all the tools for DSS data processing were transferred to the new seismic processing system recently developed at the UW seismology lab (Morozov and Smithson, 1997). This allowed me to efficiently handle DSS data and to add high performance of new UNIX-based computers (SGI Power Challenge L, SGI Indigo, Sun Sparc, and HP workstations), more versatile data analysis, color PostScript and interactive plotting programs, and an interface to PROMAX, to many Seismic UNIX programs, and currently – 3D visualization (Chubak and Morozov, 2006).

As a result of these efforts, the PNE datasets shown in Figure 1 were digitized, edited, formatted in long-record (PASSCAL extension) SEGY formats, and delivered to IRIS for unrestricted dissemination. We have also created tools for exporting the datasets in CSS3.0 or NNSA-schema databases. As an example, http://seisweb.usask.ca/downloads/Craton-chem.tar.gz is such a compressed UNIX archive of the chemical-explosion CRATON dataset in NNSA format. Other datasets may be available in this format on a request.

5. DATASET DESCRIPTIONS

In the following descriptions, we present brief summaries of the datasets, location maps, and formats of the data CD's as they were submitted to IRIS. Because of a different database organization, the records may be distributed by IRIS DMC in different formats.

5.1. Project AGATE

Project AGATE included five seismic lines two of which recorded PNE AGATE. Locations of and the approximate lengths of the lines are (Figure 5 and Figure 6):

Line 1: Czech Lip – Pai-Hoi; 689 km;

Line 2: White Sea – Vorkuta; 1045 km;

Line 3: Dvina Lip – river Mezen'; 280 km;

Line 4: River Onega - Czech Lip; 715 km;

Line 5: River Vaga – White Sea, 730 km.

Data acquired by SpetzGeofisika in 1985.

1 PNEs and 36 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

<u>*Dataset format:*</u>

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as `CHANNEL, and the FFIDs` correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
agate-<shot_number>-<component_index>.segy
```

where shot_number is the number of the shot. Shot numbers are 1, 2, 3 for the PNE (RIFT-1, 2, and 3, respectively; Figure 1). Fir chemical shots, shot numbers correspond to the number of the nearest receiver. The component_index is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

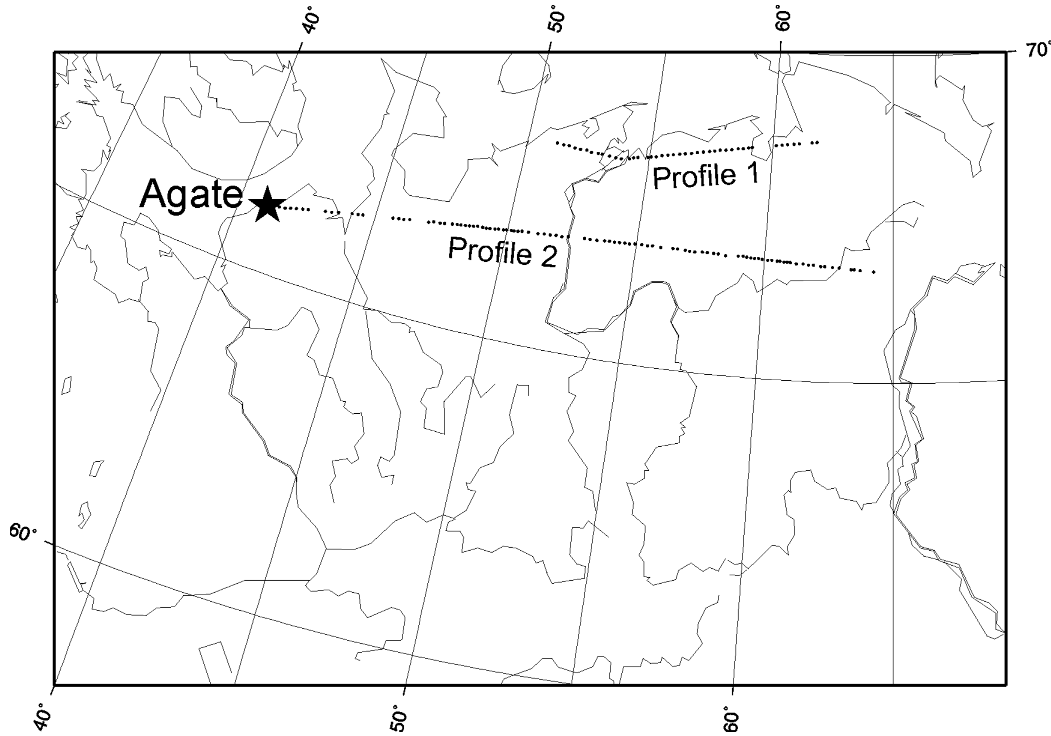

Figure 5. Profiles recording PNE AGATE.

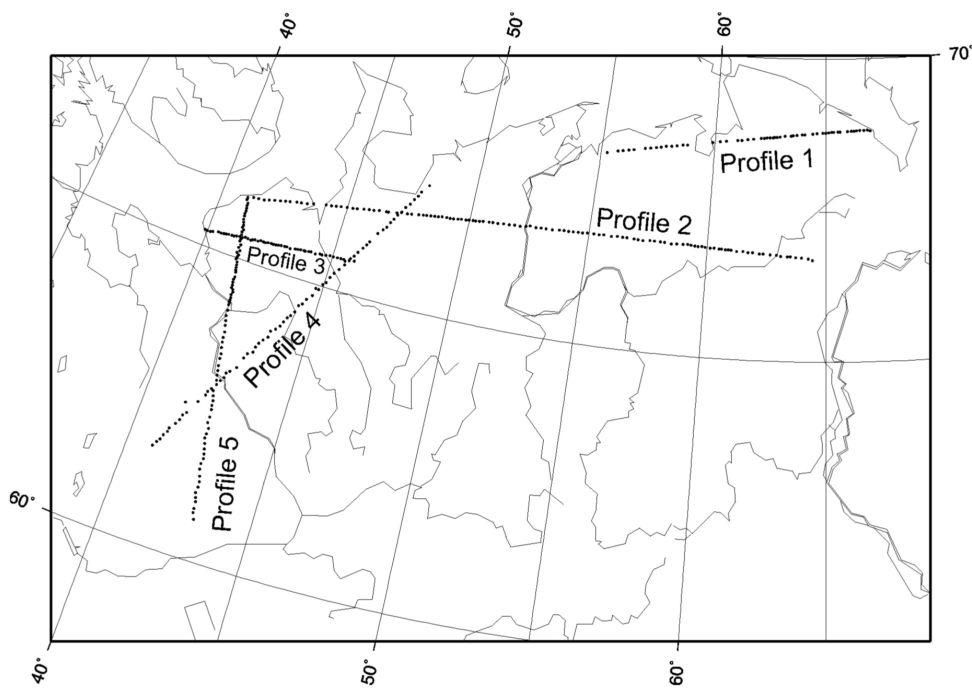

Figure 6. Chemical-explosion lines of AGATE project.

5.2. Project BATHOLITH-1

Project BATHOLITH-1 included three seismic profiles one of which recorded PNE BATHOLITH-1. Locations and the approximate lengths of the profiles are (Figure 7 and Figure 8):

Profile 1: town Kolpashevo – Kudu-Kuel'; 2497 km km; 35 chemical shot points;

Profile 2: river Chelonchen – Taas-Yuryakh; 251 km; 8 shot points;

Profile 3: river Chelonchen - Khornintsy; 367 km; 9 shot points;

Data were acquired by SpetzGeofisika in 1980.

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of DSS PNE records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in trace headers. Recording station numbers were loaded in SEGY headers as `CHANNEL`, and the `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot.

For the PNEs, file names follow the following convention:

```
bath-<PNE_number>-<line_number>-<component_index>.segy
```

Figure 2. Chemical-explosion lines of projects BATHOLITH (eastern lines, red) 1 and 2 (blue).

where `line_number` is the number of recording line (Figure 2). For chemical shots, the files are named as follows:

```
bath-<line_number>-<shot_number>-<component_index>.segy
```

where line numbers are shown in Figure 1, and shot numbers correspond to the number of the nearest receiver. The `component_index` is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

On the CDs, chemical shot data from the different lines were placed into subdirectories `line-1-1`, `line-1-2`, etc., numbered according to the project and line numbers.

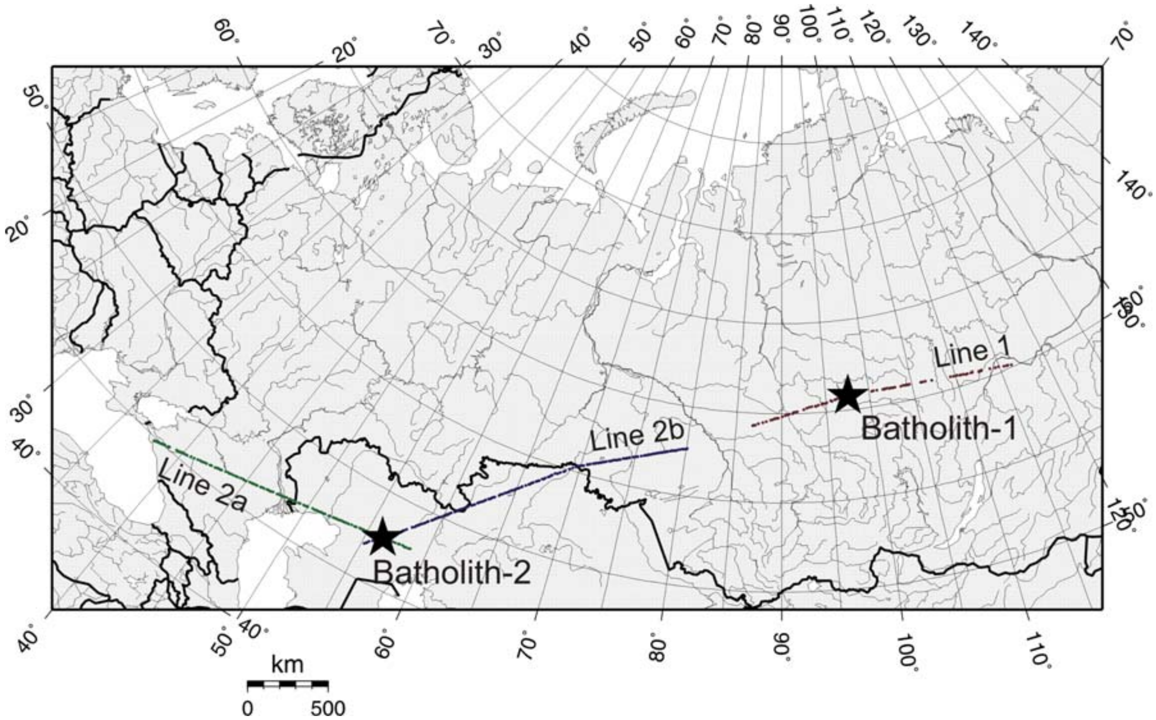

Figure 7. PNE lines of projects BATHOLITH-1 and 2. Stars are the PNEs. Triangles indicate the locations of three-component recorders.

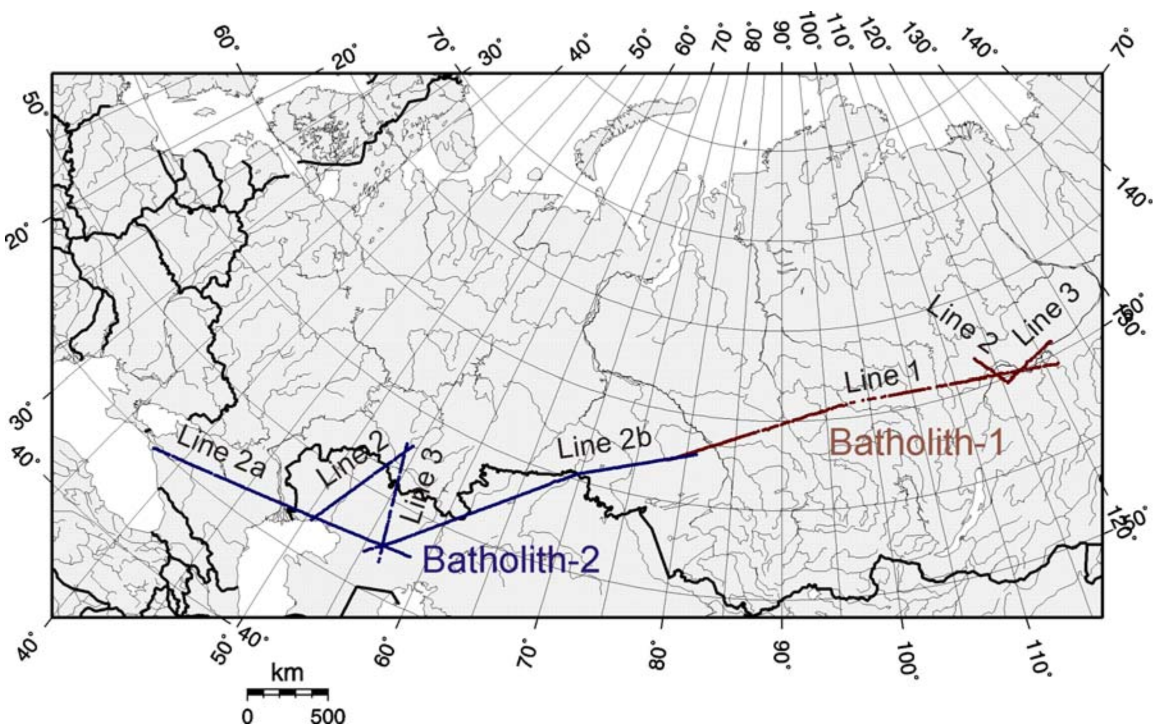

Figure 8. Chemical-explosion lines of projects BATHOLITH-1 and 2.

5.3. Project BATHOLITH-2

Project BATHOLITH-2 included four seismic profiles one of which recorded PNE BATHOLITH-2. Locations and approximate lengths of the profiles are (see Figure 7 and Figure 8 in the preceding section):

Profile 2: town Manash – town Karachanganak, 750 km, 15 shots;

Profile 2a: city Krasnodar – town Emba; 3690 km (with profile 2b), 26 chemical shot points;

Profile 2b: town Emba - town Kolpashevo; 38 shot points;

Profile 3: town Emba - city Orenburg; 725 km; 10 shot points;

Figure 1. PNE lines of projects BATHOLITH-1 and 2.

Data were acquired by SpetzGeofisika in 1987.

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of DSS PNE records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in trace headers. Recording station numbers were loaded in SEGY headers as `CHANNEL`, and the `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot.

For the PNEs, file names follow the following convention:

```
bath-<PNE_number>-<line_number>-<component_index>.segy
```

where `line_number` is the number of recording line (Figure 2). For chemical shots, the files are named as follows:

```
bath-<line_number>-<shot_number>-<component_index>.segy
```

where line numbers are shown in Figure 1, and shot numbers correspond to the number of the nearest receiver. The component_index is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

On the CDs, chemical shot data from the different lines were placed into subdirectories `line-1-1`, `line-1-2`, etc., numbered according to the project and line numbers.

5.4. Project BAZALT-1

Project BAZALT-1 included three seismic profiles recording chemical explosions. Locations and the approximate lengths of the lines are (Figure 9):
Profile 1A: city Krasnovodsk – town Mari, 16 source points, 757 km.
Profile 1B: town Mari – town Muruntau – city Abakan, 48 source points, 2818 km;
Profile 2: town Termez – Aral Sea – town Emba, 23 source points, 1590 km.

Data acquired by Spetzgeofisika in 1989.
87 chemical explosions of 3000-5000 kg
Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (generally numbered starting from the West, Figure 9) are loaded in SEGY headers as `CHANNEL`, and `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
baz-1-<line>-<shot_number>-<component_index>.segy
```

where `line` is the line name (1A, 1B, or 2), and `shot_number` is the number of the shot. Shots are numbered by the position of the nearest receiver station. Shot numbers correspond to the number of the nearest receiver. The component index is '`v`' for the vertical (upward), '`r`' for radial (directed away from the shot), and '`t`' for the transverse (directed to the right when looking away from the shot point).

Data records are started at times = offset/10 and truncated at 200-sec lengths. Time sampling intervals are typically 10 ms (stored in SEGY headers).

For quality control purposes, data CDs also contain subdirectories with PostScript plots of the corresponding data sections. As the plots are automatically generated, plotting parameters may not be optimal for every record, yet they give an idea of data density and general quality.

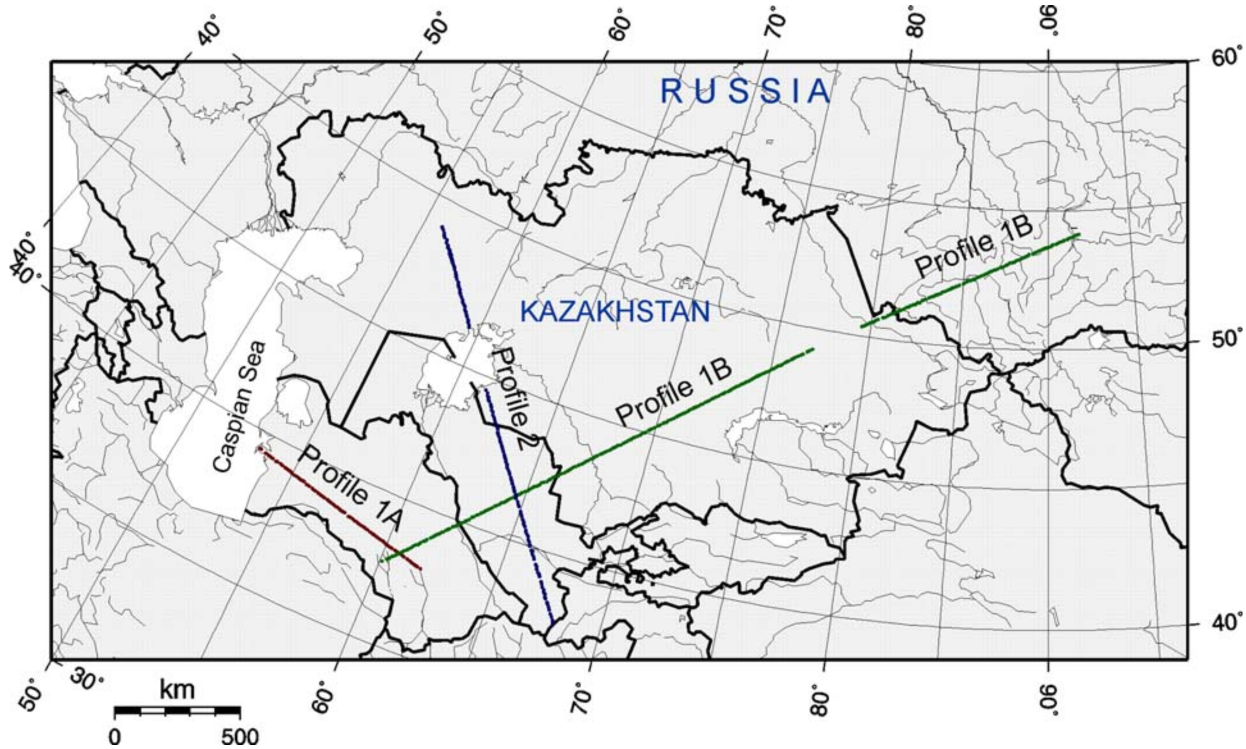

Figure 9. Three chemical-explosion profiles of project BAZALT-1. Small colored triangles show 3-component receiver stations.

5.5. Project BAZALT-2

Project BAZALT-2 included two seismic profiles recording chemical explosions. Locations and approximate lengths of the lines are (Figure 10):
Profile 1: town Abakan – town Tinda – Tatar Strait, 68 source points, 3387 km;
Profile 2: town Tinda – town Amurzet; 19 source points.

Data acquired by SpetzGeofisika in 1990.
87 chemical explosions of 3000-5000 kg
Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (generally numbered starting from the West, Figure 10) are loaded in SEGY headers as `CHANNEL`, and `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
baz-2-<line>-<shot_number>-<component_index>.segy
```

where `line` is the line name (1A, 1B, or 2), and `shot_number` is the number of the shot. Shots are numbered by the position of the nearest receiver station. Shot numbers correspond to the number of the nearest receiver. The component index is '`v`' for the vertical (upward), '`r`' for radial (directed away from the shot), and '`t`' for the transverse (directed to the right when looking away from the shot point).

Data records are started at times = offset/10 and truncated at 200-sec lengths. Time sampling intervals are typically 10 ms (stored in SEGY headers).

For quality control purposes, data CDs also contain subdirectories with PostScript plots of the corresponding data sections. As the plots are automatically generated, plotting parameters may not be optimal for every record, yet they give an idea of data density and general quality.

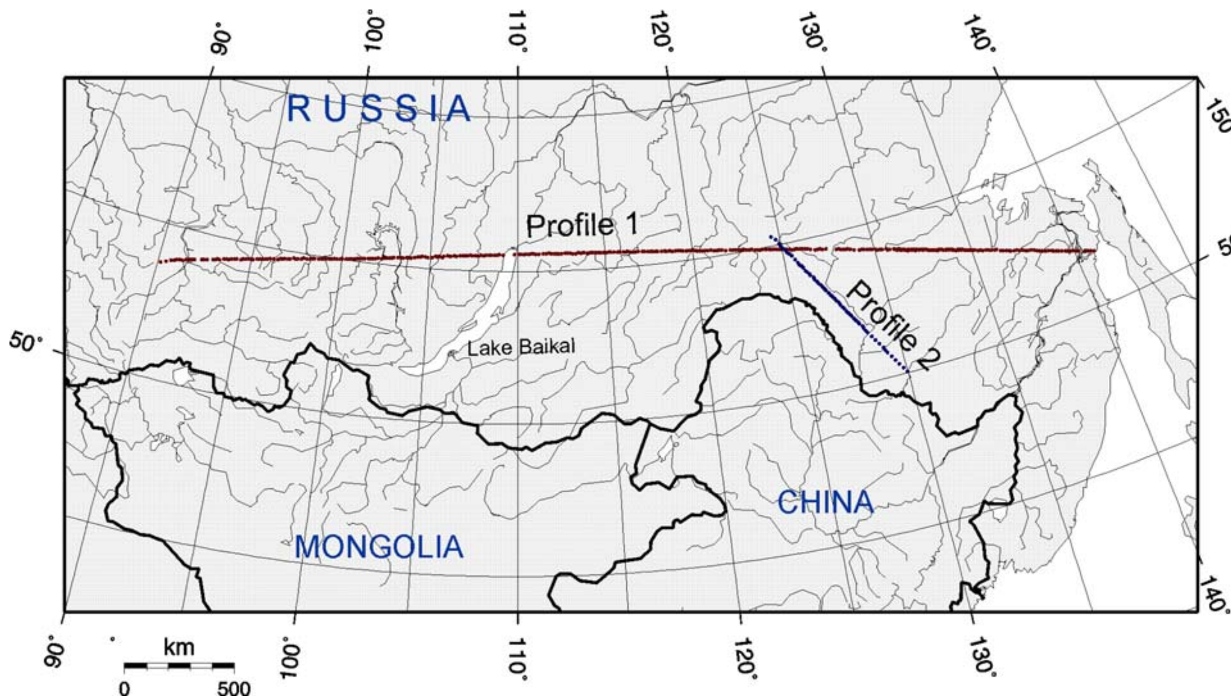

Figure 10. Location map of three chemical-explosion profiles of project BAZALT-2. Small colored triangles show the 3-component receiver stations.

5.6. Project CRATON

Location: Berezovo-Ust'-May (see map in Figure 11)

Acquired by Center GEON, 1978-1980

Profile length: approximately 3900 km

4 PNEs and 30 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as CHANNEL, and the FFIDs correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
crat-<shot_number>-<component_index>.segy
```

where shot_number is the number of the PNE (1,2,3, or 4; Figure 1), and the component_number is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

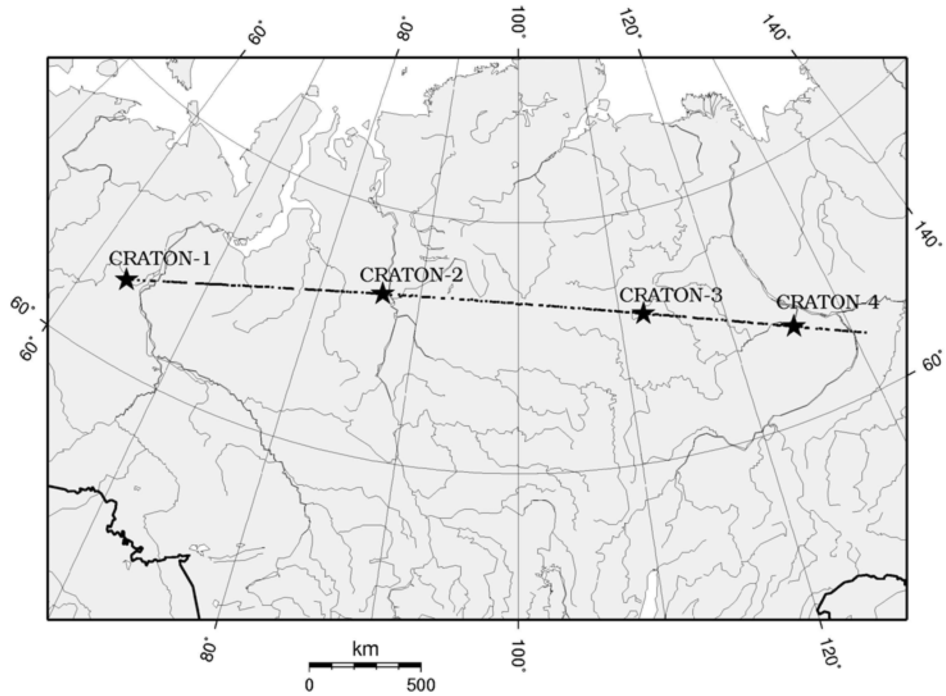

Figure 11. Location map of profile CRATON in Northern Asia. Stars indicate the PNEs, small triangles are 3-component recording sites.

5.7. Project KIMBERLITE

Location: town Khanty-Mansyisk — river Lena (Figure 12)

Acquired by SpetzGeofisika, 1979

Profile length: approximately 3100 km

3 PNEs and 36 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as `CHANNEL, and the FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
kimb-<shot_number>-<component_index>.segy
```

where shot_`number` is the number of the shot. Shot numbers are 1,3,4 for the PNEs (KIMBERLITE-1, 3, and 4, respectively; Figure 1). Fir chemical shots, shot numbers correspond to the number of the nearest receiver. The `component_index` is '`v`' for the vertical (upward), '`r`' for radial (directed away from the shot), and '`t`' for the transverse (directed to the right when looking away from the shot point).

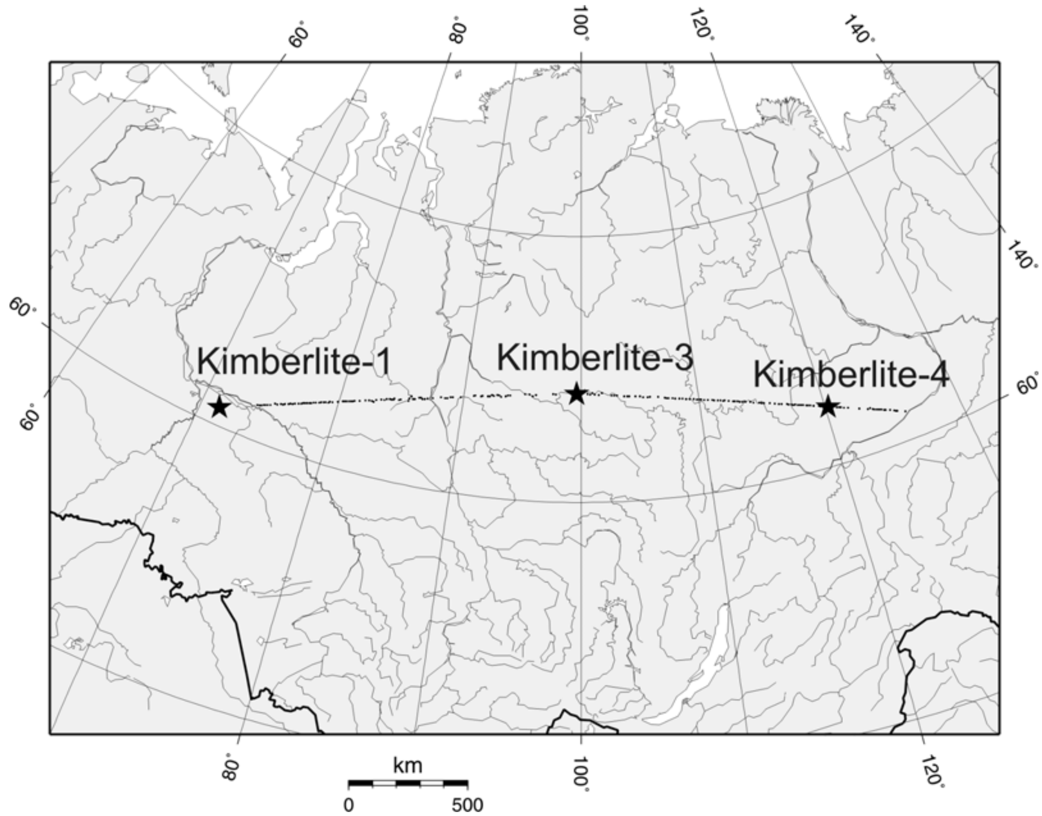

Figure 12. Location map of profile KIMBERLITE in Siberia. Stars indicate the PNEs, small triangles are 3-component recording sites.

5.8. Project METEORITE

Location: Dixon city — town Khilok (Figure 13)

Acquired by Spetzgeofisika, 1977

Profile length: approximately 2980 km

4 PNEs (Figure 1)

In addition, records from ~30 chemical explosions of 3000-5000 kg were acquired but could not be digitized due to poor record preservation.

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the NW, Figure 1) are loaded in SEGY headers as `CHANNEL`, and the `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
meteor-<shot_number>-<component_index>.segy
```

where `shot_number` is the number of the shot. Shot numbers are 2,3,4, and 5 for the PNEs (METORITE-2, 3, 4, and 5, respectively; Figure 13). The `component_index` is '`v`' for the vertical (upward), '`r`' for radial (directed away from the corresponding shot), and '`t`' for the transverse (directed to the right when looking away from the shot point).

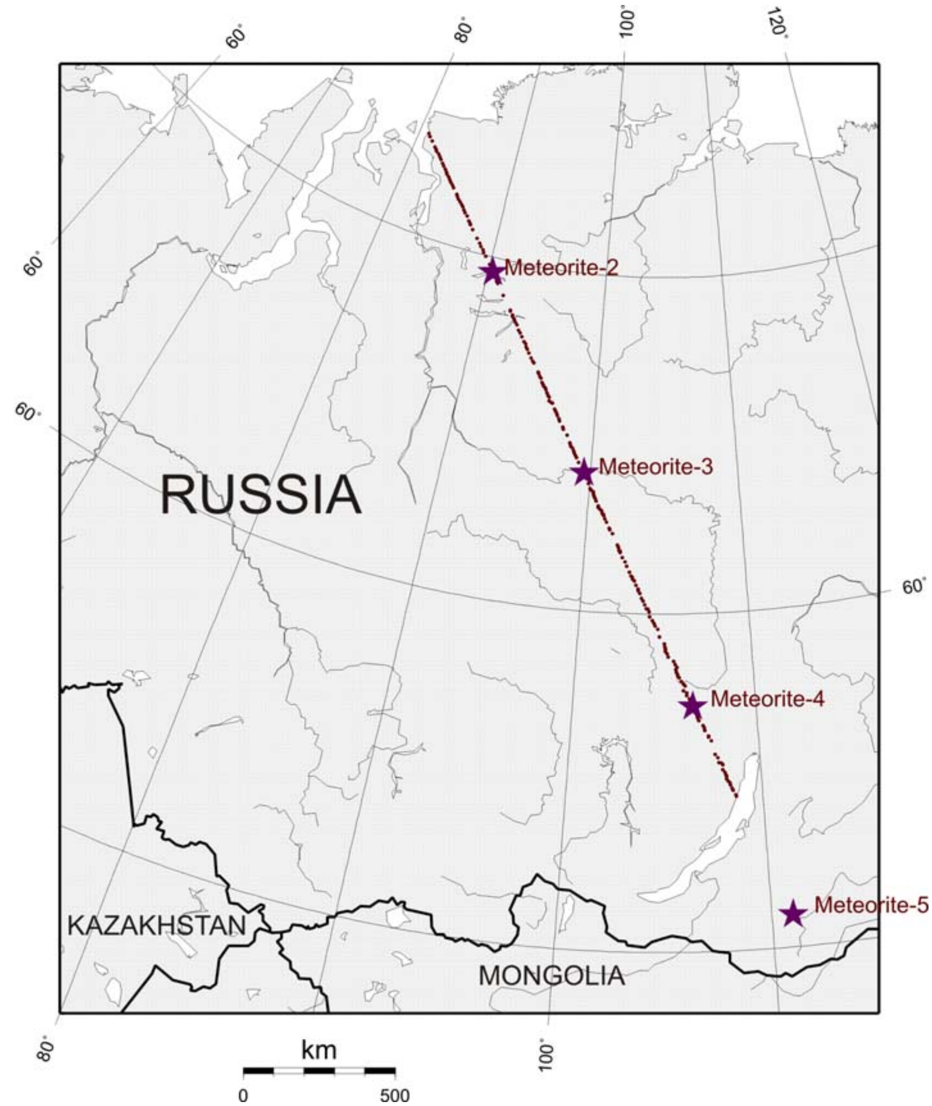

Figure 13. Location map of profile METEORITE in Siberia. Labeled stars indicate the PNEs, small triangles are the 3-component recording sites.

5.9. Project QUARTZ

The profile “Quartz” (Murmansk-Kizil) is one of 14 major DSS profiles acquired in the USSR during the fulfillment of the DSS program. The profile, completed by SpetzGeofisika in 1984-87, extends 3850 km across several major tectonic units of northern Eurasia (Zonenshain et al., 1990). Starting at the northwest end of the profile, these units are (Figure 14):

1) The East European Platform (770 km), including 440 km of the Baltic Shield. The oldest rocks of the East European Platform are early Archean; the last significant event here was the intrusion of rapakivi granites about 1600 Ma ago.

2) The Timan Belt (120 km of the profile), which is a late Precambrian fold belt or a suture between eastern Europe and Barentsia.

3) The Pechora Basin (360 km), which underwent a number of extensional events from early Devonian to late Cretaceous or early Palaeogene.

4) The Uralian Belt (260 km), formed at the end of the Paleozoic and the beginning of the Mesozoic.

5) The West Siberian Basin (1540 km) -a broad extensional basin with very thick Triassic and Holocene sediments.

6) The Altai-Sayan Foldbelt (900 km of the profile) -- an active Alpine belt which underwent several phases of deformation from the early to middle Cambrian to the Permian throughout the Paleozoic.

Recordings were made with about 400 3-component seismographs from 3 PNEs (located at about 1130, 2050 and 2820 km from the northwestern end of the profile, Figure 1) and 51 chemical explosions (3 of which returned poor data). The average station spacing was about 10-15 km.

Extensive analysis of the data from the profile “Quartz” was published to date (see an incomplete bibliography below). These publications cover the 1-D and 2-D mantle structure, attenuation, upper-mantle scattering (vigorously discussed several years ago), crustal imaging using receiver functions, and also coda analysis and modeling.

Dataset format:

The data are provided in standard SEGY format using IBM floating point values for data samples. Geographic coordinates of the shots and receivers, and offsets (in meters) are loaded in SEGY headers. Recording station numbers (numbered from the NW, Figure 1) are loaded in the headers as `CHANNEL` numbers, the `FFID`s correspond to shot numbers. Each file contains a single component or recordings from one shot. File naming nomenclature is as follows:

```
quartz-<shot_number>-<component_index>.segy
```

where `shot_number` id 2, 3, or 4 for the PNEs (Figure 1) and the number of the nearest recording station for chemical shots. `Component_number` is `v` for the vertical, `r`, for inline component, and `t` for cross-line.

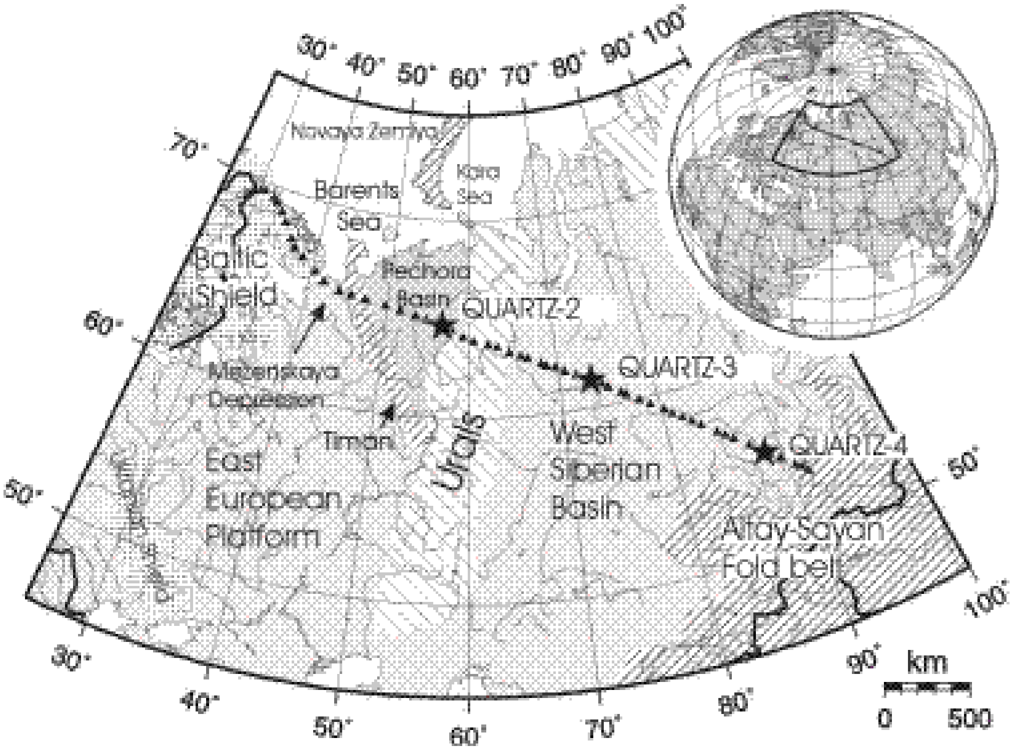

Figure 14. Location map of profile QUARTZ and the major tectonic units of NW Eurasia. Stars are the locations of PNEs, triangles are the chemical shots.

5.10. Project RIFT

Location: Yamal-Peninsula — town Kyahta (Lake Baikal; Figure 15).

Acquired by SpetzGeofisika, 1982-1983

Profile length: approximately 2980 km

3 PNEs and 36 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

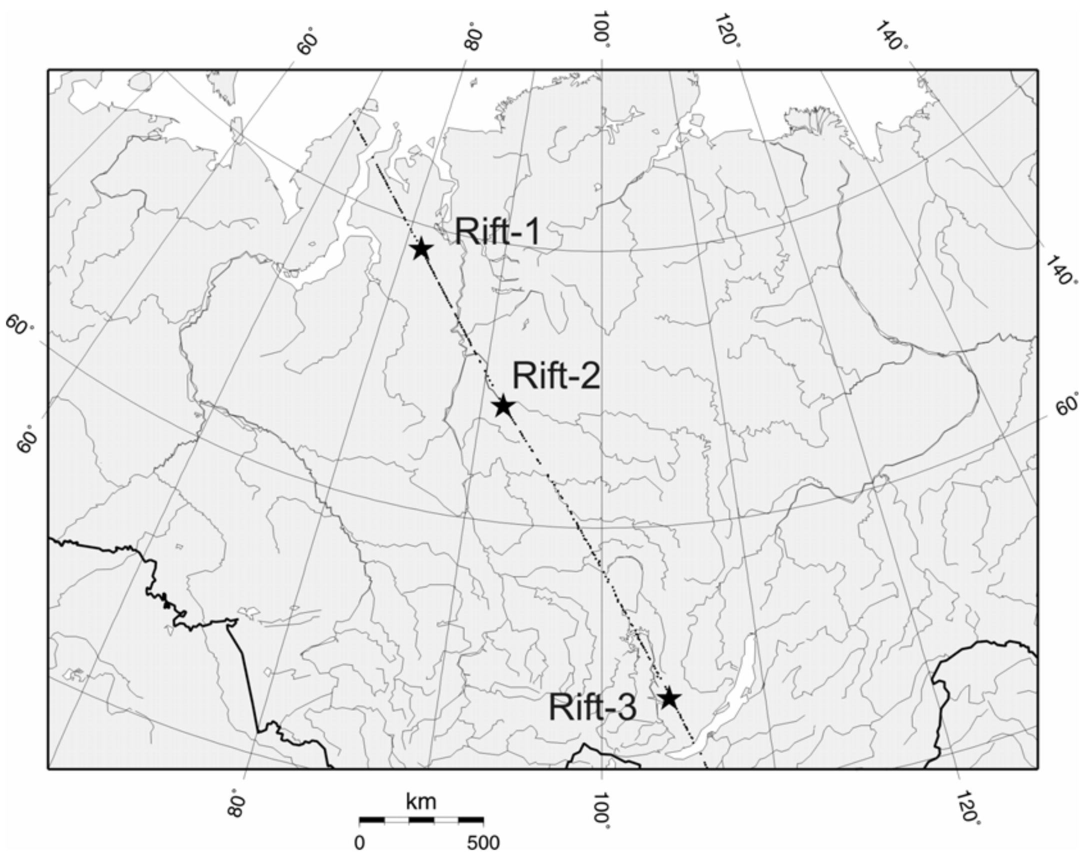

Figure 15. Location map of profile RIFT. Stars indicate the PNEs, small triangles are 3-component recording sites.

Data format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as `CHANNEL, and the FFIDs` correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
rift-<shot_number>-<component_index>.segy
```

where shot_`number` is the number of the shot. Shot numbers are 1,2,3 for the PNEs (RIFT-1, 2, and 3, respectively; Figure 1). Fir chemical shots, shot numbers correspond to the number of the nearest receiver. The `component_index` is '`v`' for the vertical (upward), '`r`' for radial (directed away from the shot), and '`t`' for the transverse (directed to the right when looking away from the shot point).

5.11. Projects RUBY-1 and RUBY-2

Project RUBY included two lines, referred to as Ruby-1 and Ruby-2 below (Figure 16). The data were acquired by the Spetzgeofisika in 1988-1989. Both PNEs were recorded by both lines.

5.11.1 Line Ruby1

Location: town Kostomuksha — town Semipalatinsk (Figure 16)

Profile length: approximately 3050 km

2 PNEs and 27 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

5.11.2 Line Ruby2

Location: town Nizhniy Tagil — town Urengoi (Figure 16).

Profile length: approximately 1850 km

2 PNEs and 26 chemical explosions of 3000-5000 kg

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Figure 16. Location map of the two lines of project RUBY. Stars indicate the PNEs, small triangles are 3-component recording sites.

On the accompanying CD, the data for both PNEs are provided in directory `ruby`, and the chemical explosions are given separately for the two lines, in directories `ruby1` and `ruby2`. PostScript plots of all sections are also provided in the corresponding subdirectories. All plots were generated by an automated procedure for quality control purposes and may not be very well optimized for viewing or interpretation.

Dataset format:

The data format is identical to that of QUARTZ, CRATON, KIMBERLITE, and RIFT records delivered earlier. The data are provided in standard SEGY format using the IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as `CHANNEL`, and the `FFID`s correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

ruby-<shot_number>-<line>-<component_index>.segy	for PNEs
ruby1-<shot_number>-<component_index>.segy or ruby2-<shot_number>-<component_index>.segy	for chemical explosions

where shot_number is the number of the shot. Shot numbers are 1,2,3 for the PNEs (RUBY-1, and 2, respectively; Figure 1). For the PNEs, the line numbers (1 or 2) are appended to differentiate between the in-line and fan recordings. For chemical shots, shot numbers correspond to the number of the nearest receiver. The component_index is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

5.12. Project SPAT

Location: Barnaul city – town Severo-Yeniseysk – town Tiksi (Figure 17).

Data acquired by Spetzgeofisika in 1981.

Profile length: 3091 km

1 PNE and 39 chemical explosions of 3000-5000 kg; only chemical explosions are provided in this distribution.

Recording systems: Portable 3-component analogue systems TAIGA and CHEREPAKHA, 1-Hz sensors

Dataset format:

Data format is identical to that of QUARTZ records delivered earlier. The data are provided in standard SEGY format using IBM floating point representation of data values. Geographic coordinates of shots and receivers (in degrees), and offsets (in meters) are loaded in data headers. Recording station numbers (numbering starting from the West, Figure 1) are loaded in SEGY headers as `CHANNEL, and the FFIDs` correspond to shot numbers. Each data file contains a single component of recordings from one shot. File names follow the following convention:

```
spat-<shot_number>-<component_index>.segy
```

where `shot_number` is the number of the shot. Shot numbers correspond to the number of the nearest receiver station. The `component_index` is 'v' for the vertical (upward), 'r' for radial (directed away from the shot), and 't' for the transverse (directed to the right when looking away from the shot point).

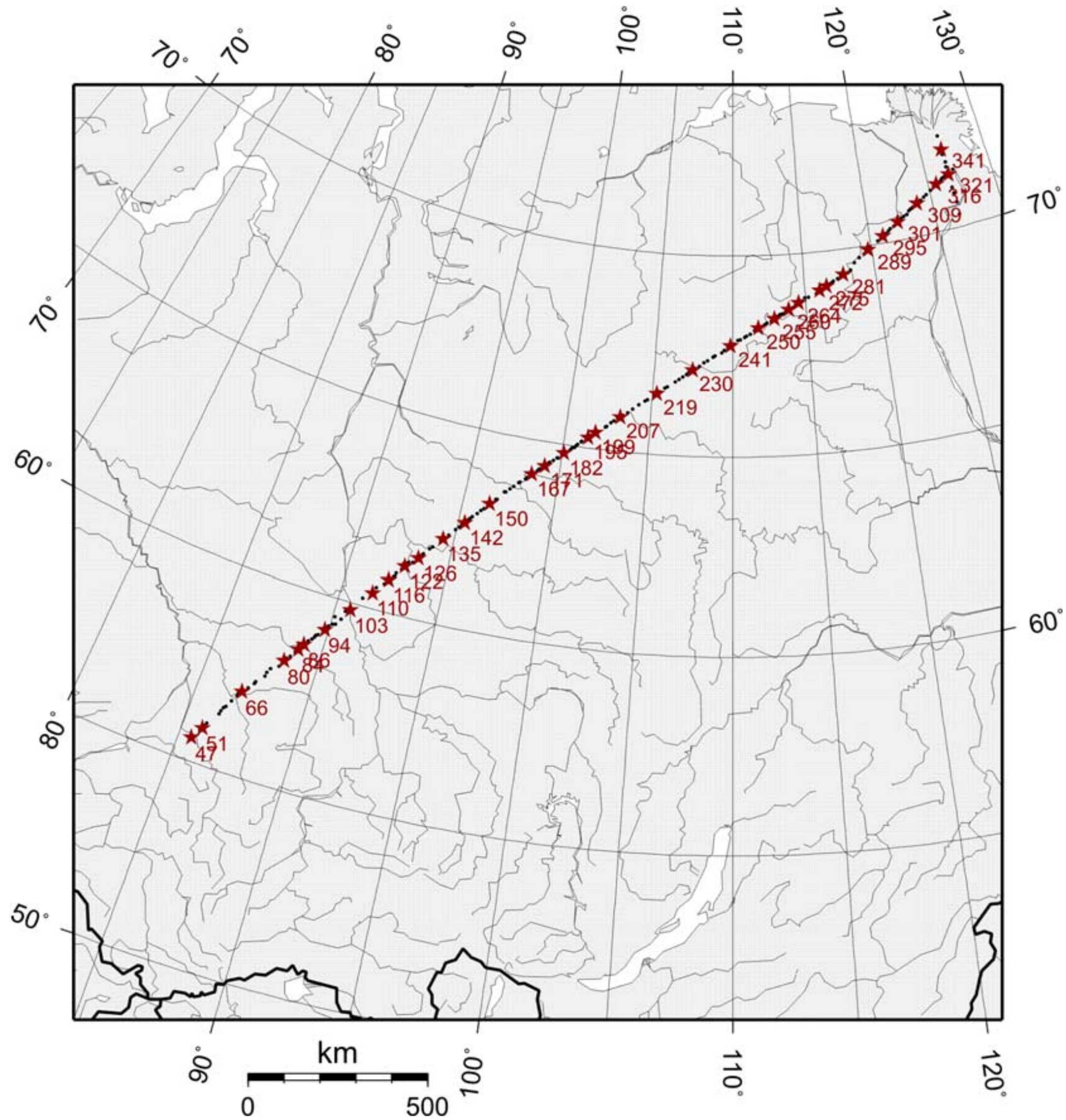

Figure 17. **Location of profile SPAT. Small black triangles are recording stations. Labeled red starts are chemical explosions. Labels indicate station numbers of the explosions (loaded as `FFID` headers in SEGY files).**

6. CONCLUSIONS AND FURTHER PERSPECTIVES

Combination of the results based on the DSS PNE projects of this study (velocity, reflectivity, Receiver Functions, mantle attenuation, *Lg Q*, *P*- and *Lg* coda *Q*, scattering, phase amplitude ratios, empirical first-arrival travel times) makes the area of PNE profiling one of the best-constrained seismically at short periods. This conclusion applies to both fundamental and applied (monitoring) research areas.

The success of any geophysical investigation is determined by the data. In this project, we have preserved and made publicly available the complete seismic datasets from roughly 80% of the DSS PNE data that was still recoverable. Acquisition of such data, across similar distances at high latitudes, would be extremely expensive, and in the cases of PNEs, completely impossible today. Thus we strongly recommend that the remaining DSS PNE data are properly digitized and archived. The only remaining profiles that still could be digitized are SPAT (one PNE and earthquake datasets), BITUM, and PRICASPIY (2 profiles; Figure 1). Digitization of these records would complete preservation of the historic DSS PNE datasets. Note that SPAT and BITUM lines are particularly important, as they cross the Siberian platform in NE-SW direction which is so far not represented in our dataset (Figure 1). Multiple lines of project PRICASPIY also cover the Pre-Caspian Depression in different directions, in the vicinity of PNE BATOLITH-2 (Figure 1).

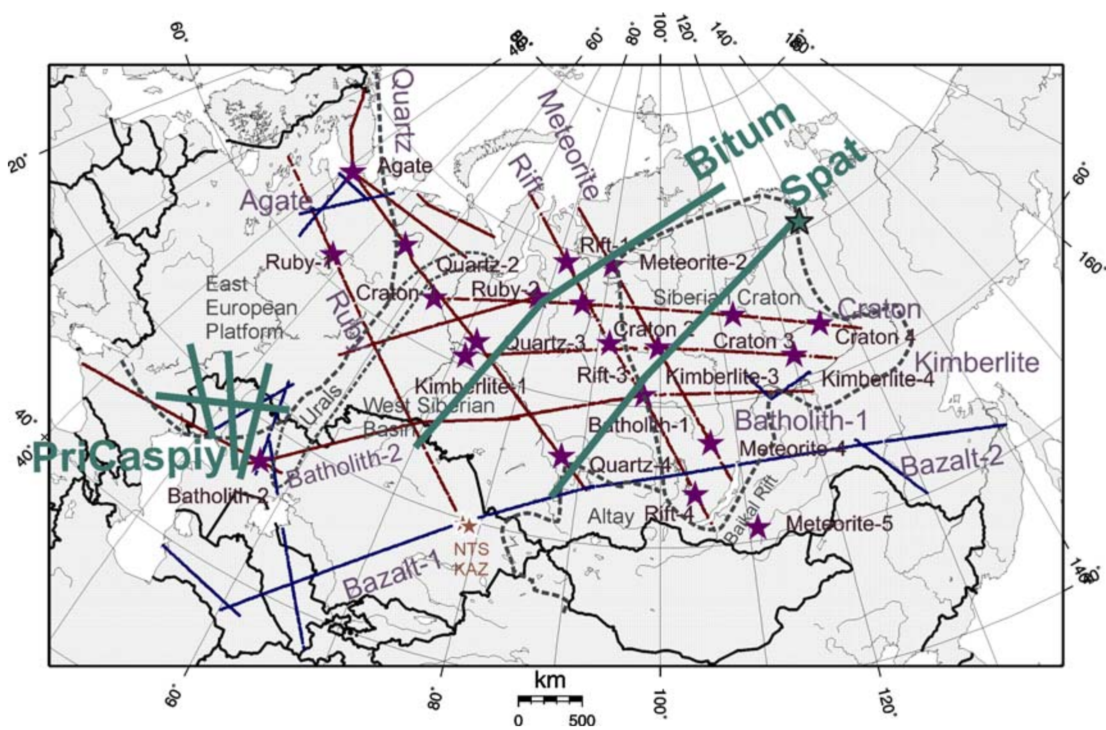

Figure 18. Map of DSS PNE profiling as in Figure 1 with the three remaining projects still available for digitization: BITUM, PRICASPIY, and SPAT (green lines). From profile SPAT, we have delivered the chemical-explosion dataset as a part of the present project, and its PNE and earthquake dataset still remain to be digitized..

At the same time, the depth of the datasets is far from being exhausted. Only QUARTZ dataset has been studied thoroughly and from various standpoints, and complemented by CRATON, KIMBERLITE, METEORITE, RIFT, and RUBY in only limited studies. Most of the critical (and also most tedious and difficult) work on detailed inversion of the crustal and mantle structure was still only done by Russian groups (Pavlenkova and Yegorkin). Apart from QUARTZ, modern inversion techniques have been still insufficiently applied, and the very interesting fan lines from PNEs RUBY-1, RUBY-2, and AGATE have not been analyzed at all. Chemical-explosion datasets are still underutilized, as well as PNEs AGATE, BATHOLITH, and SPAT. Integration of the results in a true 3-D model still remains to be performed, and this model should incorporate the various empirical attributes and be capable of numerical simulations. These are the directions in which, as we hope, the work will be continued in the future.

7. RECENT PUBLICATIONS USING DSS PNE RECORDS

Data analysis was not a part of this project. However, DSS PNE records were extensively studied in the past two decades, in part owing to the availability of the data resulting from this project.

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7.1 Other Relevant Publications

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